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**Annual Progress Report for ONR Research Grant # N00014-99-1-0904**

**Principal Investigator:** Frank Carroll, M.D.

**Institution:** Vanderbilt University Medical Center

**Grant Title:** Research Proposal on Prototype Development of a Compact, Pulsed Hard X-ray Source for Medical Imaging and Research in Biological and Material Sciences.

**Reporting Period:** July 1, 1999 to June 30, 2000

**Award Period:** July 1, 1999 thru June 30, 2001

**Objective:** To develop a source of pulsed, tunable, monochromatic x-rays using an RF accelerator and terawatt laser for use in medical imaging and treatment.

**Approach:** The electron beam from an RF linac will be used to scatter infrared beams from a terawatt laser using the phenomenon of inverse Compton Scattering to produce beams of pulsed, tunable, monochromatic x-rays. These x-rays will be in the hard x-ray range from 0 to 50 keV (fundamental) with capability of easily reaching hundreds of keV.

**Accomplishments:**

The design of the accelerator, including the photo-cathode, gun, modulator, klystron, beamline and beam dump has successfully been completed. These items are currently being fabricated by Advanced Energy Systems (AES) of Long Island, NY. The klystron, with a backup unit, has been shipped and is expected to arrive at the Vanderbilt MFEL facility, where the machine is being constructed, on July 1<sup>st</sup> 2000.

However, the modulator has been redesigned and is being built "in-house", given the expertise currently available at the Vanderbilt MFEL. Utilization of the MFEL personnel will allow for customization and construction of a more robust and compact modulator than currently available from outside vendors, and at a significant savings. Additionally, a superconducting solenoid magnet will now be used to focus the electron beam into the interaction zone, to improve the quality of the electron beam when focused to the smallest spot sizes.

Delivery of the accelerator to Vanderbilt is scheduled for early August, with installation during the month of August. Commissioning is scheduled for September 2000. Modifications to the laboratory for appropriate power, water and floor loading are currently underway. These will be completed late June 2000.

In the summer of 1999, competitive design studies were commissioned between Positive Light and Light Age to examine both glass and alexandrite terawatt laser systems. A review of both systems resulted in the selection of Positive Light to build a ten-joule terawatt system using Nd-glass amplifiers with a Ti-sapphire front end. A contract was let and long

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lead-time items such as gratings were ordered. All vendors are meeting scheduled delivery times. The vacuum chamber for the pulse compressor grating will also be constructed by MFEL personnel hired by MXISystems, Inc. Again, this is linked to "in-house" expertise and to preferences in building materials and vacuum pumping options.

The terawatt laser is under construction at this time. Personnel from MXISystems, Inc. will be traveling to Positive Light's manufacturing facility during the last two weeks of July to learn to operate and troubleshoot the laser system. At the end of the two-week period, the laser will be packed and shipped to Vanderbilt (i.e.- during the first week of August).

Installation and commissioning of the laser is also scheduled for August/September 2000.

The interaction zone is being built at Vanderbilt, and is essentially a clone of the device used on the Vanderbilt MFEL at the time when that device produced monochromatic X-rays in 1998.

As of this date, the project is ahead of schedule and on budget.

**Imaging:**

We have been successful in producing three-dimensional reconstructions of phantoms, mice and rats using monochromatized beams in a scanning geometry, as well as in fan-beam geometries. Comparison studies using polychromatic radiation in similar geometries are used as comparisons. CT images of nude mice (using 48-90 views instead of the standard 360 views) have also been reconstructed with resolutions of 35-50 microns. The imaging chain has been modified to include a detector using new nanocrystal imaging technology, which allows resolutions down to 6 microns. New reconstruction algorithms have been written to accommodate the geometry and absorption characteristics of the unique monochromatic beams, and to collect and massage data on 35 slices simultaneously with less computational overhead.

Currently under investigation is the comparison of standard mammography dose, spatial resolution and contrast resolution as compared to monochromatized beams and to beams that are to be bounced off multi-layered mirrors for the purposes of both plain film mammography and phase contrast imaging using Laue crystals.

Also under investigation is longitudinal *in vivo* x-ray microscopy of the lung as a tool to study drug effects over time within a single animal rather than necessitating large numbers of animals to study these effects as is now practiced. Small animal imaging is also being developed to perform volumetric 3-D acquisitions for use in functional genomics, studying "knockout" mice.

**Publications:**

1. Paschal CB, Carroll FE, Worrell JA, Mendenhall MH, Traeger RH, Waters JW, Brzymialkiewicz CN, Banks GA. *Volumetric Monochromatic X-ray Tomography of the Lungs.* SPIE Proceedings Biomedical Applications of Free-Electron Lasers Vol. 3925, pp2-7, January 2000
2. Carroll FE, Waters JW, Mendenhall M, Traeger RH, Paschal CB, Brau C. *Pulsed Tunable Monochromatic X-rays and Their Role in Medicine.* Bulletin of the American Physical Society Vol. 45 #2, 54 April 2000.

**Disclosures and Patents:**

1. Mosaic Crystal Rotator. Patent applied for.
2. Inverse Compton Scattering Device using linear accelerator and terawatt laser. Patent applied for.

# REPORT DOCUMENTATION PAGE

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<b>13. SUPPLEMENTARY NOTES</b>						
<b>14. ABSTRACT</b> <p>The prototype development is essentially complete and the accelerator and laser are under construction. Delivery of both systems is scheduled for August 2000. System commissioning is scheduled for September 2000. Applications research has produced three-dimensional CT images of animals at resolutions between 35 and 50 microns using monochromatized fan beam geometries.</p> <p>Currently under investigation is comparison of standard mammography with high resolution, two and three-dimension monochromatic plain film and phase contrast imaging.</p>						
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